THE EFFECT OF DEEP UNLOADINGS ON THE J_R RESISTANCE CURVE

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The effect of deep unloadings on fracture toughness was examined for a HSLA ASTM A710 steel where toughness was evaluated in the elastic-plastic regime by the J_R curve test method. During the J_R curve evaluation following modes were applied: (1) occasional full unloadings ($P_{min} = 0$); (2) occasional unloadings with compression to full closure of the load-line displacement ($V = 0$; $P_{min} < 0$). The resulting J_R curves were compared with J_R curves generated for specimens tested in a standard procedure. Raising the J_R curve was judged as an increase in toughness and lowering it as a decrease.

INTRODUCTION

During standard J-integral fracture mechanics characterization tests a very careful load history is utilized. First the specimen is fatigue precracked at a low cyclic stress level and the specimen is then tested by a number of small elastic unloadings. This load history is unlikely to be reproduced in actual load histories on the J_R resistance curves.

The objective of this work is to investigate effects of occasional full unloadings ($P_{min} = 0$) and unloadings with compression to full closure of the load line displacement ($V = 0$; $P_{min} < 0$).

EXPERIMENTAL METHODS

The material used for the test program was a high strength low alloy steel (HSLA) which has an ASTM designation A710 grade A, class 3. The chemical composition for this material is presented in Table 1, and the mechanical properties are shown in Table 2. The specimens used were of 20% side grooved compact type (1TCT) with cracks in the T-L orientation as defined by ASTM E 399 (1). The J_R curve tests were conducted at room temperature and in accordance with ASTM E 1152-87 (2).

The results reported here utilized MTS-810 servo-hydraulic test machine with PDP-11 mini computer. The computer used for calculation and storing data was Tektronix Model 4051. Typical load histories are shown in Fig. 1 and 2.

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Table 1 Chemical composition of HSLA steel A710 (wt %)

C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Nb
0.05	0.30	0.62	0.011	0.004	0.88	0.72	0.185	0.105	0.041

Table 2 Tensile properties of HSLA steel A710

Material	Yield strength $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Elongation % in 50 mm	Reduction of Area (%)
A710	645	730	27	73

ANALYSIS OF THE RESULTS

To get J_R curves for presented load histories J-integral was calculated according to the expression (1):

$$J_{(i)} = \frac{(K_i)^2(1-\nu^2)}{E} + J_{pl(i)} \qquad (1)$$

where stress intensity factor, K_i, is

$$K_{(i)} = \left[P_i/(BB_NW)^{1/2}\right]f(a_i/W) \qquad (2)$$

and plastic component of J is:

$$J_{pl(i)} = \left[J_{pl(i-1)} + \left(\frac{\eta_i}{b_i}\right)\frac{A_{pl(i)} - A_{pl(i-1)}}{B_N}\right]\left[1 - \frac{\gamma_i}{b_i}(a_i - a_{i-1})\right] \qquad (3)$$

In Eq.3, for CT specimens, $\eta = 2 + (0.522)b_i/W$, $\gamma = 1 + (0.76)b_i/W$, where W -specimen width, b_i -instantaneous length of remaining ligament, B_N -minimum specimen thickness, a_i -instantaneous crack length and $A_{pl(i)} - A_{pl(i-1)}$ is the increment of plastic area under the load versus load-line displacement record between lines of constant displacement at points *i*-1 and *i*.

Crack lengths are determined using unloading compliance method (2). The resulting J_R curves, together with baseline J_R curve are shown in Fig.3.

The first observation is that limited occasional number of full unloadings to nearly zero minimum loads (in this case 5) does not affect J_R curve which fall on the baseline J_R curve. On the other hand, occasional unloadings with compression to full closure of the load line displacement (V=0) lowered tear toughness on the subsequent tear steps, which is in agreement with the results of Joyce (3). In the same time, slope of the segments of such curve stayed parallel to the baseline J_R curve.

CONCLUSIONS

1. Conducted tests show complexity and problem of applicability of the J-integral as a characterization fracture parameter in the presence of the deep unloadings during the course of monotonic tearing.
2. Experiments showed that occasional unloadings with compression to full closure lower J_R curve, while full unloadings to $P_{min}=0$ does not.

3. These results do appear to support the type of analysis proposed by Kaiser (4).

REFERENCES

(1) ASTM Standard E 399-79A, *Test Method for Plane-Strain Fracture Toughness of Metallic Materials*, Annual Book of ASTM Standards, Part 10, 1987, pp.540-561, Philadelphia.

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(4) Kaiser, S., Fatigue of Engineering Materials and Structures, Vol.6, No.1, 1983. pp.33-49.

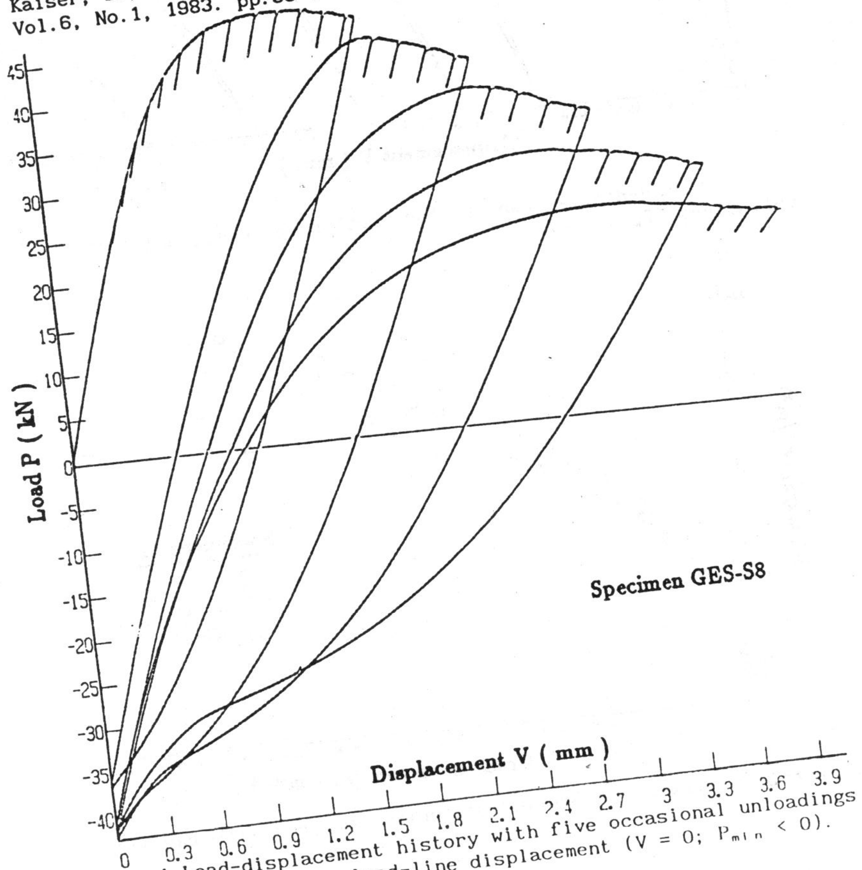

Figure 1 Load-displacement history with five occasional unloadings to full closure of the load-line displacement (V = 0; $P_{min} < 0$).

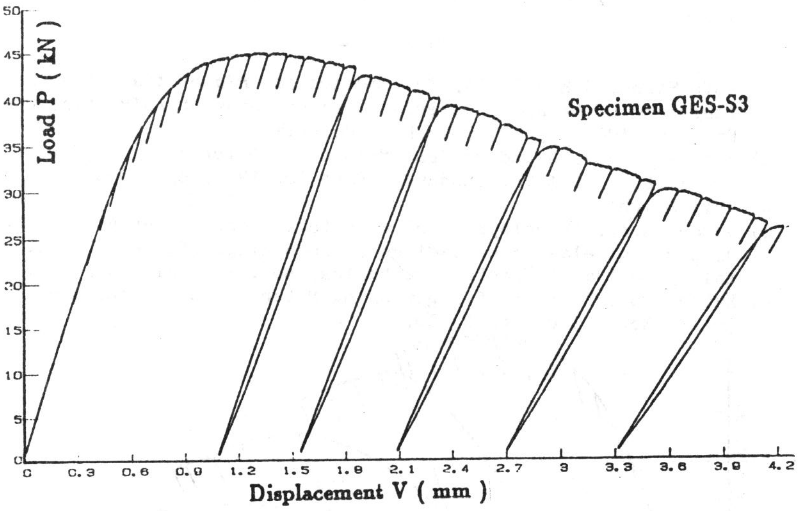

Figure 2 Load-displacement history with five occasional full unloadings (P_{min} = 0).

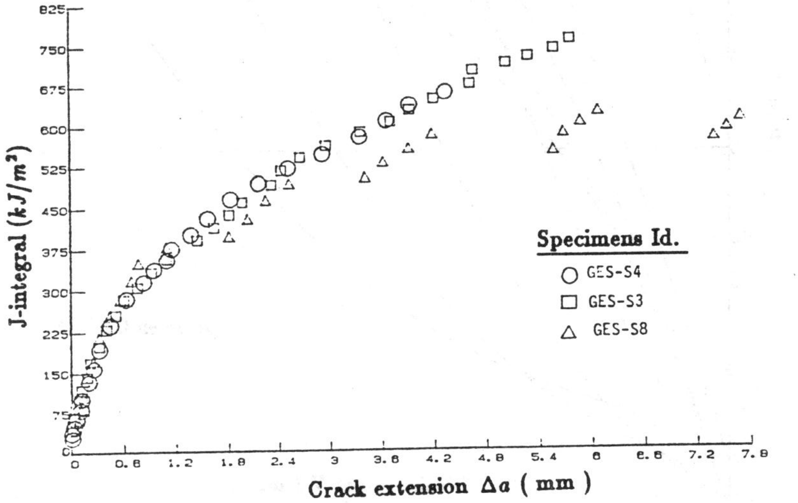

Figure 3 J_R curves for applied histories compared with baseline J_R curve.